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AN EXPERIMENT FOR DETERMINING THE STABILITY OF SURFACE COATINGS IN SPACE FLIGHT

by

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INTRODUCTION

Stability of the thermal-radiation characteristics of surfaces intended for use in thermal control systems is a prime requirement for space vehicles. Because of the difficulties involved in simulating the adverse effects of the space environment with ground-based facilities for the purpose of investigating surface coatings, testing surfaces during flight in the actual space environment appears attractive. A simple, straightforward method for measuring any changes in the thermal characteristics of surfaces resulting from exposure to conditions in space flight is to measure variations in temperature of the surfaces during exposure to sunlight, since any change in the ratio of solar absorptivity to surface emissivity (α/ϵ) will be reflected in a corresponding change in surface temperature. This paper describes an experiment of this type which is planned for inclusion on a number of satellites.

REQUIREMENTS FOR THE THERMAL-TYPE EXPERIMENT

An obvious requirement for the thermal-type emissivity experiment is that the test surface be thermally isolated, since extraneous heat losses must be minimized to provide an accurate indication of change in α/ϵ .

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To illustrate this point, the influence of heat loss on the equilibrium temperature of surfaces is shown in the first slide (1). The equilibrium surface temperature is plotted as a function of the α/ε ratio for zero heat loss and for a fixed heat loss of 5 milliwatts. Note that for a fixed heat loss and a constant emissivity the equilibrium temperature is considerably more affected as the ratio of α/ε is decreased. Also, the effect of a given heat loss on the temperature becomes greater as the emissivity is decreased. The reason for these two effects is that the heat loss becomes a greater proportion of the heat flux as the α/ε ratio is reduced, for a fixed value of ε.

A second requirement is that the test surface have a rapid response to changes in heat flux. It is desirable that the surface reach thermal equilibrium during its daytime and nighttime passages around the earth. This facilitates reduction of the data to obtain the α/ε ratio. If the thermal lag of the surface is large, its temperature history will appear somewhat as shown on the next slide (2). Also shown is the idealized temperature history of a surface with no thermal lag. In this figure, the effects of the earth's reflection and radiation are neglected for simplification, although in most cases these effects must be considered. It is apparent that large thermal lag would complicate reduction of the data, since a transient thermal analysis would be involved.

It is apparent, then, that to obtain meaningful data from an experiment of this type, heat losses from the test surfaces must be determined and the thermal lag of the system must be evaluated. The heat loss and thermal lag, of course, should be measured beforehand during ground tests.

DESCRIPTION OF EXPERIMENTAL SYSTEM

Radiation Sensor Design

The design which was established to minimize the heat losses and thermal lag of the test surfaces is illustrated in the next slide (3). The test surfaces are mounted on three small Kel-F supports. Kel-F is used as the support material because it has a very low thermal conductivity. Radiant heat losses to the mounting cup are minimized by the use of four radiation shields. All interior surfaces are polished and have an evaporated gold finish for further reducing the radiant heat exchange. Thermal lag is minimized by using a thin base plate and thin radiation shields.

Surface temperature is measured by means of a thermistor soldered to the underside of the test surface.

Mounting of Sensors

The next slide (4) shows the radiation sensors mounted in a cluster of six to permit testing several different surface finishes simultaneously. A seventh surface will serve as a reference for the other surfaces. The reference surface is designed to maintain constant radiation properties in space flight. Comparisons of the temperatures of the test surfaces with that of the reference surface will provide a basis for evaluating changes in the thermal characteristics of the test surfaces.

The design of the reference surface is indicated in the slide. The surface is composed of razor blades stacked together to form a large number of notches. This causes the incident radiation to be reflected from wall to wall of each notch a number of times before being reflected outward. The reflected radiation escaping from the system is small, since most of each reflection is absorbed by the surfaces. Because of the large number of reflections, any change in the emissivity of the individual surfaces of the notches will have only a very small effect on the overall emissivity or absorption of the reference surface. Since the notched surface is somewhat directional at large angles of incidence, the rows of razor blades are arranged in a hexagonal pattern to minimize the directional effect. Due to its high absorption, the reference surface acts as a black body, and hence is useful for evaluating the radiant energy incident upon the test surfaces.

In order to correct for heat exchanges between the test surfaces and the sensor mounts, the temperature of the base plate is measured by means of a thermistor.

Measurement of Thermal Characteristics of Sensors

As was indicated previously, it is necessary to determine the heat losses from the sensors and the thermal-lag characteristics. In addition, the absorptivity and emissivity of each of the test surfaces should be known. The equipment which is being used to measure these factors is illustrated in the next slide (5). A small cooled vacuum chamber has been arranged to receive two sensors simultaneously on a mounting base which can be rotated. The base can be heated and its temperature measured. Heating of the test surfaces can be achieved by passing current through the thermistors. The front of the chamber can be covered with either a brass plate or a quartz window.

In establishing the thermal characteristics of the sensors, the emissivity is measured as the initial step. With the brass cover plate installed, the test surface and the mount are held at the same temperature, eliminating heat exchange between the two, and are elevated above the temperature of the chamber. The heat input to the sensor thermistor, then, provides a measure of the surface emissivity, as determined from the following equation:

$$\epsilon = \frac{[illegible]}{[illegible]}$$

where

ϵ = surface emissivity

q = heat input to sensor

σ = Stefan-Boltzmann constant

A = area of sensor

T_s = surface temperature

T_c = chamber temperature

The emissivity is measured at several values of surface temperature to establish any dependence of emissivity on temperature.

With the emissivity thus established, the heat-exchange relationship between the test surface and the mounting cup can be determined by holding the surface and mount at different temperatures. Since the amount of heat lost externally by radiation from the surface to the chamber is known from the previous measurements, the heat exchange from surface to mount can be readily determined. Values must be measured over a range of temperature difference and temperature level, since the rate of heat exchange is a function of both these parameters.

Thermal-lag characteristics can be determined from measurements of the rate of temperature rise of the test surface upon application of a step heat input to the thermistor. This should be done for various values of temperature difference between the surface and mount, since the radiation-shield system contributes to the thermal lag of the sensor.

A measure of surface absorptivity can be obtained by replacing the brass cover plate with the quartz window and radiating the test surfaces with sunlight. From measurement of the equilibrium surface temperature, the ratio of α/ε can be deduced, and from the previous measurement of emissivity, the absorptivity can be determined. In this procedure, it is necessary to know the amount of incident radiation, and for this purpose, simultaneous measurements are made with the black-body reference surface alongside the test surface. Measurements of the specular absorption can be made by rotating the surfaces so that they view the sun at an angle. It is realized, of course, that some of the solar energy is absorbed by the atmosphere and the quartz window, but, since most of the solar energy will be transmitted, a reasonably accurate value of absorptivity can be obtained.

In addition to the measurements of emissivity and absorptivity of the test surfaces in the vacuum chamber, the reflectivity of the surfaces will be measured by means of a Perkin-Elmer Model 13 spectrophotometer. Calculations of emissivity and absorptivity of the surfaces will be made from the reflectivity measurements over wavelengths from 2000 angstroms to 40 microns.

Data Acquisition

Temperatures of the sensors will be telemetered to ground periodically during the flight. To conserve telemetry channels, all temperatures will be transmitted on one channel by means of a solid-state commutator switch. The switch contains ten points. Seven of these points are from the thermistors measuring the temperatures of the test surfaces, and one is from the thermistor measuring the base temperature of the sensor mounts for heat-balance corrections. The remaining two points are from standard calibrating resistances, representing two levels of thermistor temperature.

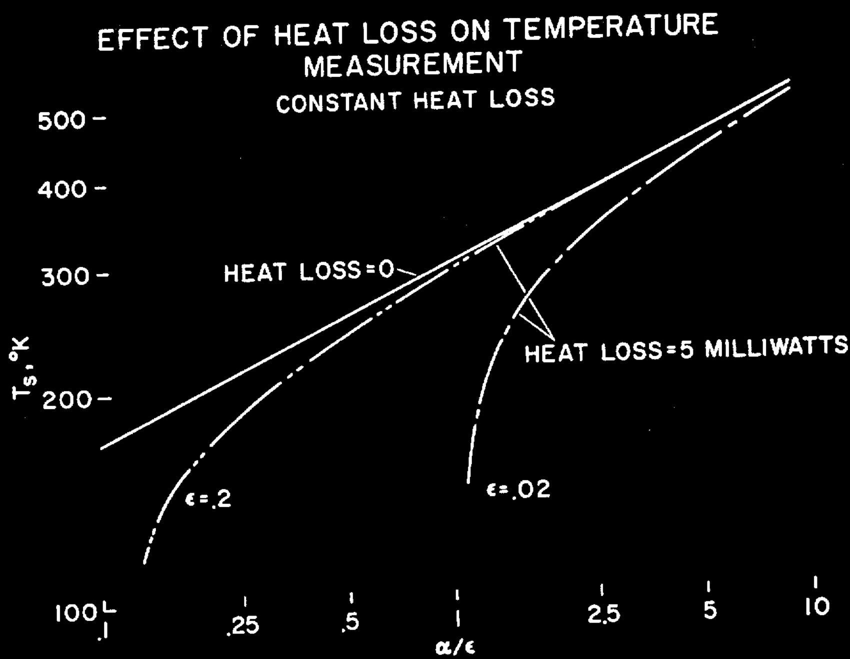

Figure 1.

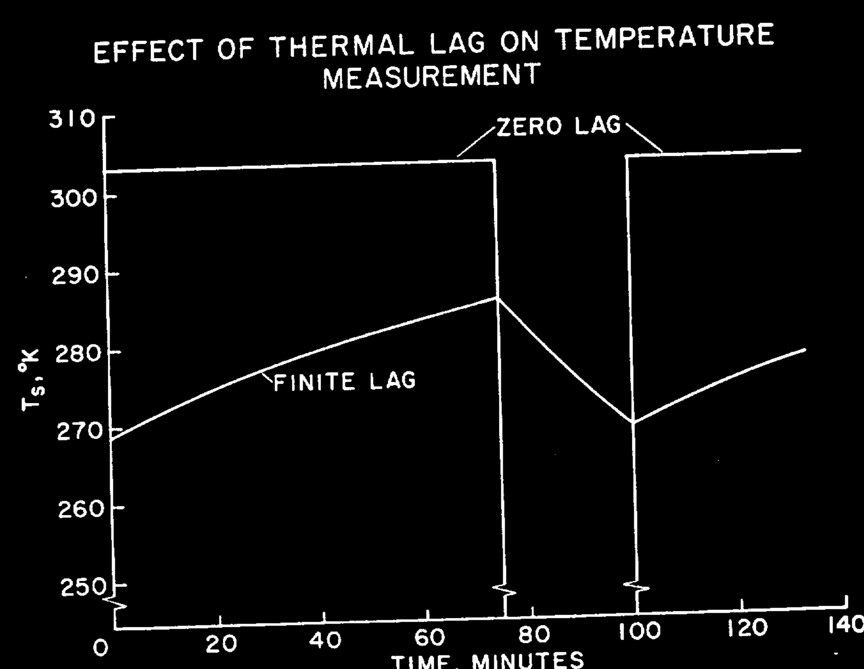

Figure 2.

CONSTRUCTION OF RADIATION SENSORS

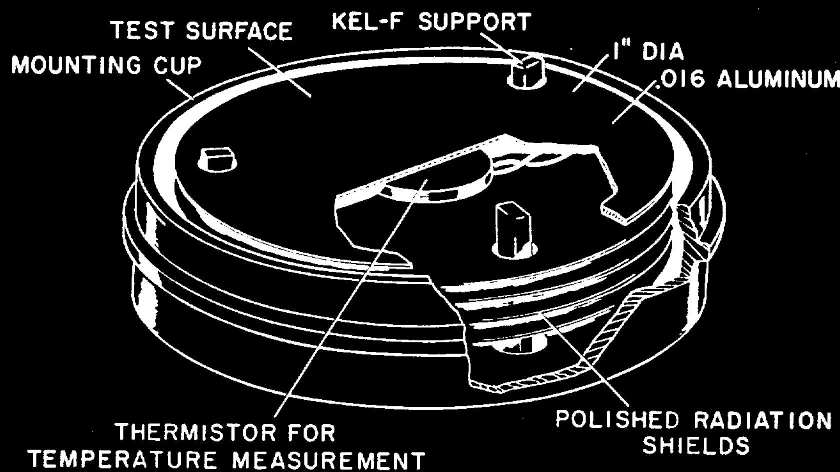

Figure 3.

MOUNTING OF RADIATION SENSORS

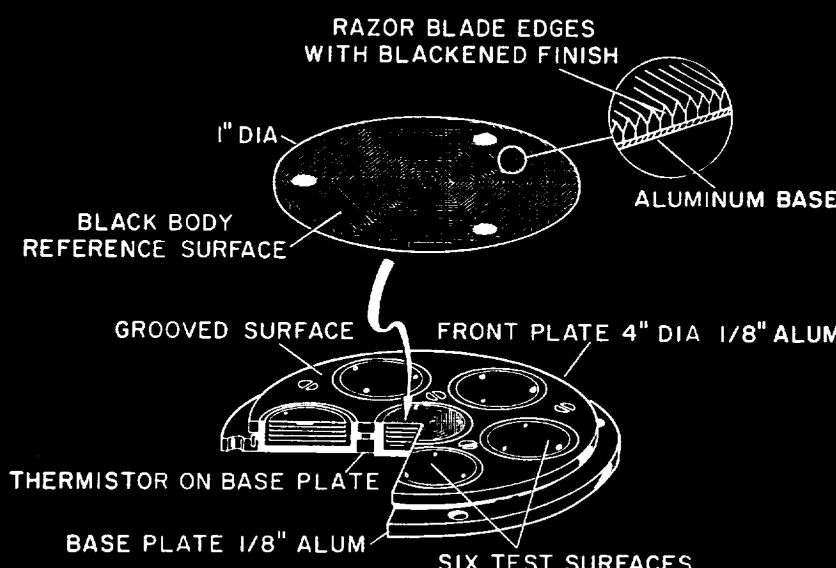

Figure 4.

EQUIPMENT FOR MEASURING THERMAL CHARACTERISTICS OF SENSORS

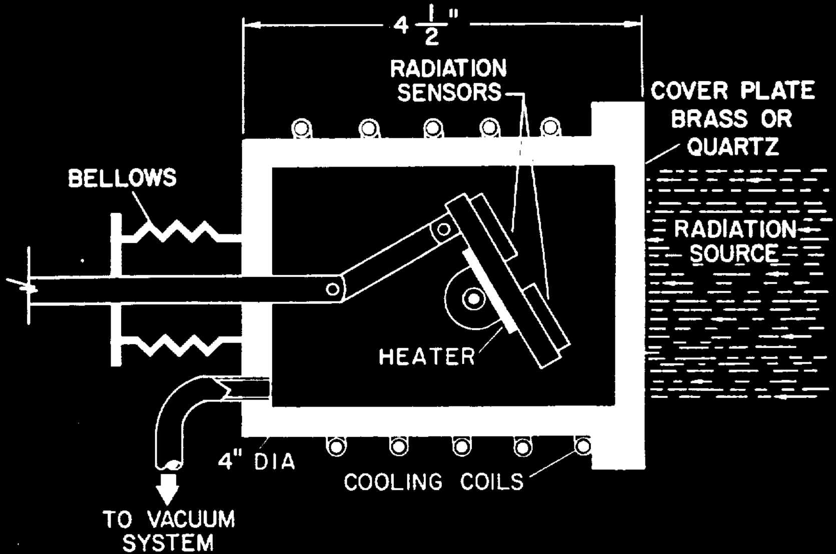

Figure 5.